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Issues of Matrix Six –Phased Converters: Technical Review

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(Abstract) One of the main components of power electronics is matrix converters. A matrix converter is an Ac to AC converter, the structure of which is made up of two-way switches. This converter can be used to feed an AC current with a desirable AC voltage. Matrix converter is a powerful AC/AC converter for the application of induction motor drives with sinusoidal input currents and no DC-link capacitor. It offers remarkable advantages over other alternatives in applications requiring improved utility interaction and critical weight/volume reduction. In this paper, after the initial introduction and classification of the AC/AC converter, firstly the advantages, disadvantages and other particular problems related to the matrix converter have been presented. Then technical review on related issues of induction motor drive fed by matrix converters (MC) is presented. The first discussions presented the special difficulties involved in matrix converters. These are partly conceptual, partly concerning circuit topology, and current commutation technique. Secondly, different types of control and matrix converter control techniques based on the Spatial Vector Modulation (SVM) technique have been discussed. The third discussion describes the hardware development modes studies. And finally, the matrix converter has been simulated using MATLAB software, and output voltage and input current has been obtained with the help of modulation matrices.

Keywords: Matrix Converter; Current Commutation; Modulation; Harmonic Losses.

1. Introduction

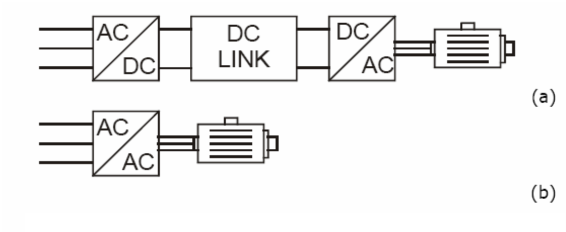
A matrix converter is an Ac to AC converter, the structure of which is made up of two-way switches. This converter can be used to feed an AC current with a desirable AC voltage. This action is performed by two way switches for the first time. The AC to AC matrix converter was proposed for the first time by Pelly and Gyugyi in 1976. After that, Alesina and Venturini designed a matrix converter using a generalized high frequency switching strategy in 1989 [2]. The converter has also attracted the industry application and the technical development has been further accelerated because of a strong demand in power quality, energy efficiency and downsizing of the converters [17]. Alesina and Venturini (1989) introduce a mathematical approach of main issues. It gives an analytical expression of duty-ratio values as functions of input voltages and desired output voltages but still has two major limitations; the knowledge of the load power factor is required and the maximum input-output voltage ratio decreases severely when input and output power factors differ. Montazeri and Khaburi in [39] introduce method to select the most appropriate voltage vector with respect to the error of the torque. The standard look-up table for direct torque control by matrix converters is improved in order to include the small, medium and large voltage vectors of Matrix Converters. With the new look-up table and new hysteresis comparator with seven levels output the system will differentiate between small, medium and large torque errors and consequently reduce the electromagnetic torque ripple and output current THD. In this paper, the current trend of MC is covered. These include:

1) Advantages and disadvantages of matrix converters. Their classification and the development of the Mc Circuit.
2) Mc Topology and protective issues.
3) Types of control methods based on modulation of spatial vector.
4) Simulating the six-phase matrix converter and obtaining output voltage and input current with the aid of modulation matrix.

1-1 Matrix Converters can be classified as follows:

1) The Direct Version consists of SQ and matrix converters.
2) Whereas, the indirect version consists of (a) AC/AC converters with a capacitive DC Link and (b) AC/AC converter with an inductance link, and (c) AC/AC converter with a capacitive-inductance DC link.

“ Figure”.1 shows these Schematics:



(Figure.1. a) Indirect b) direct)

In most industrial applications, the conversion of AC/AC is needed, thus necessitating the use of AC/AC converters, as well. The AC/AC converter takes in electrical energy and changes the form of the input system wave into a waveform of different magnitude and phase. Converters can be divided in two basic categories: One is the indirect AC converter and the other, the direct energy converter. The indirect converters have two phases of rectification. First, AC to DC and in the second, in order to generate the required variable AC, DC is converted to AC. In direct converters, conversion of AC into AC takes place directly and an AC variable is to be found at output. In indirect converters, the variation in the power of the input and the output must be stored for an instant in an energy storing element in the converter. This element is the inductance energy storage or capacitance, but on the other hand there is no need for this energy-storing element in direct converters.

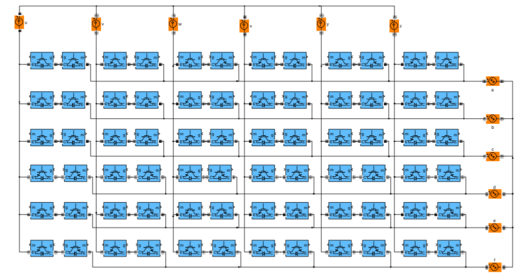
1-2 The matrix model has many advantages, including:

1)The number of elements that store energy is less and therefore less space is taken up.
2)Output voltage is generated with a magnitude of variable frequency.
3)Sinusoidal output and output current have the least harmony.
4)The power circuit is simple and straight forward.
5)The input power coefficient is controllable.
6)Quadruple functions
7) A high proportion of transferring input output voltage is sinusoidal.

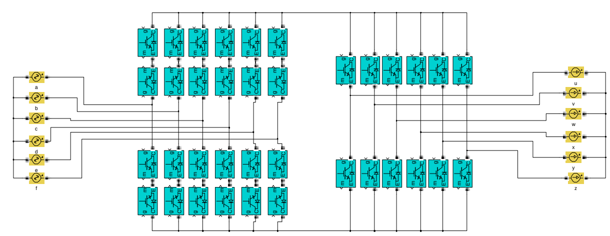
Although having the above advantages, several important faults have not allowed this type of converter to find its appropriate place in industry according to initial expectations. These could be summarized as:

1) Difficulty in dismantling controls
2) Absence of all-purpose two-way switches working in high frequency.
3) Inherent limitations in input-output voltage.
4) Exposed switches.

2. Circuit topologies and protection control



(Figure.2. Direct matrix converter)



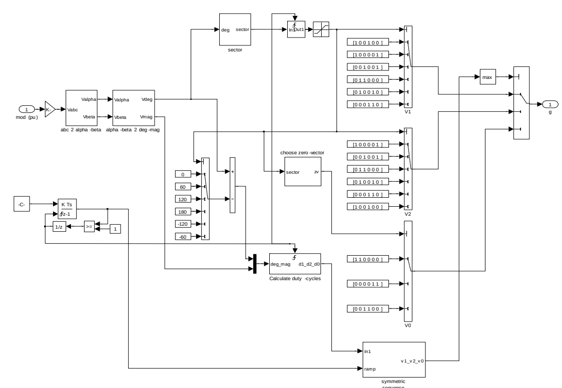
(Figure.3. Indirect matrix conversion)

Various MC topologies have been studied since 1970 [7]. The research is not only concerned on conventional direct matrix converters (DMC), presented in “ Figure.1” , but an indirect matrix converter (IMC)presented in “ Figure.2” has also been studied [16]. In an ideal case DMC and IMC provide similar performance with identical control system. However, in real motor drives some differences in output voltages and power losses occur caused by different main circuits, whose effects are increased by different commutation methods needed to provide safe operation. “ Figure”. 3 shows Clamp circuit. Thus the output voltages of the converters do not follow their references similarly but the effects of non-idealities are more severe in the IMC than in the DMC. In addition, the efficiency of the IMC is smaller than DMC under most loading situations tested. Other derivative topologies of MC are the sparse matrix converter (SMC) [14]. SMC avoid the multistep commutation procedure of the conventional MC, improving system reliability in industrial operations. Its principal application is in highly compact integrated AC drives. SMC topology is constructed from 15 transistors, 18 diodes, and 7 isolated driver potentials (IDP). Compared to the DMC topology provides identical functionality, but with a reduced number of power switches and the option of employing an improved zero DC-link current commutation scheme, which provides lower control complexity and higher safety and reliability. The very sparse matrix converter (VSMC) topology is developed from 12 transistors, 30 diodes, and 10 isolated driver potentials. There

are no limitations in functionality compared to the DMC and SMC. Compared to SMC there are fewer transistors but higher conduction losses due to the increased number of diodes in the conduction paths. The significant limitation of this converter topology compared to SMC is the restriction of its maximal phase displacement between input voltage and input current which is restricted to“ ± 30° ”. The other topology is Z-source matrix converter which comprises of two types structure; voltage-fed and current fed. [25] proposed a type of three phase AC-AC Z-Source converters which are derived from MC theories.

MC needs to be protected against the over voltages and the over currents that might be destructive for its semiconductor devices. An effective and robust protection scheme plays an important role in the implementation of a stable and reliable power converter. In [12, 13] a type of protection circuit was proposed, which consists of input and output diode bridges, an electrolytic capacitor, and its charge and discharge circuit. Other disadvantages that could be added to these could include: its electronic capacitor is of a large volume causing the life cycle of the system to be shortened and the discharge circuit used in it increases the number of parts used. On the other hand, a varistor protection and a suppressor diode protection were proposed in [15]. Even one of the switches is at fault and cannot be used; the proposed strategy is still useful. a small-capacity clamping circuit is necessary. Different from the usual clamping circuit, is necessary.

The control strategy of MC was proposed by an Italian Venturini in 1979. The maximum line-to-line output voltage of the MC must not be greater than the minimum line-to-line input voltage. This condition gives the maximum output voltage intrinsic limit of “0.866” [21]. The objective of any MC modulation strategy is to obtain the target output voltages and sinusoidal input currents at a controlled input power factor subject to the constraints of not open circuiting any output phase and of not short circuiting any two input phases. Various modulation strategies have been formulated to meet this objective. The modulation is mainly divided into the following four kinds: direct transformation method, hysteresis current method, two voltage method, and space vector modulation (SVM) method. [3] presented a detailed comparative study between the two different scalar approaches namely, Venturini and Roy applied to the control of an induction motor. The study dealt with the motor current, speed and torque performance response with respect to both techniques. [6] proposed a control strategy of scalar modulation with three intervals and vector control technique. The advantages of MC and vector control are combined in this technique. Most researchers focus on the SVM method [10], which is a more mature control strategy. SVM technique is utilized to calculate the duty cycles of the active voltage vectors that must be applied in each switching cycle period, in order to satisfy the input and output requirements. SVM technique use simpler algorithm compared with the proposed technique by Venturini. The SVM technique allows a direct understanding of switching patterns and their characteristics from the viewpoint of analysis and control. The modulation strategy is capable of controlling not only the output wave, but also the input current wave, as well as modifying the input power factor. [1] proposed the SVM algorithm derived from Indirect Transfer approach (ITF) to yield higher rms output voltage. The modulation of input current is shown in Figure 4; the output voltage modulation is similar to VSI. The improvement of the pulse pattern for the output phase voltage during carrier cycle was proposed in [23]. In the proposed modulation method, the duty factors of the output pattern obtained by SVM are converted into the duty factor of every switch of the MC. In [22] the modified direct SVM method without using zero space vector was proposed to reduce the common mode voltage which currently exists in the entire modern converters. [18] proposed a combined controller to implement both SVM and direct field oriented control (DFOC). SVM is employed to regulate the input/output sinusoidal currents of MC and the DFOC to ensure the good performance of induction motor. [4] derived a particular set of parameters of the generalized scalar pulse width modulation (GSPWM) resulting in the common mode voltage reduction (CMVR) technique. The technique uses the three possible zero vectors switching configurations to minimize the common mode voltage in the MC in all range of the voltage ratio up to “ 86.6%”, without significant increase of the input currents harmonic and without the complex algebraic and trigonometric calculations inherent of the (direct space-vector modulation) DSVM



(Figure. 4. Input current modulation)

[9] combined the SVM-MC with the rotor field oriented vector control of induction motor. A two degree of freedom controller was proposed by [8] in an adjustable speed control system and a position control system to obtain good transient responses and good load disturbance rejection abilities. The study of the high dynamic performance speed-flux tracking field oriented control algorithm was presented in [5]. [24] established the model of MC in d-q frame via PARK transformation.

3. Parameters of the Matrix Converter

In matrix converters, the output voltage, the input current and

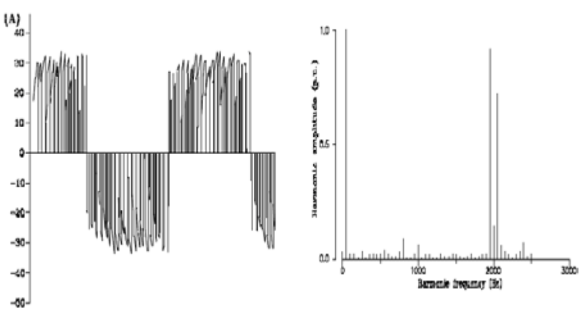
the power coefficient are controlled.

3.1 Output voltage control

As there is no element to store energy between the input and output of the converter, the output voltage is directly generated from the input voltage. Any wave form of the output voltage is obtained by consecutive sampling of the input wave form converter.

3.2 Input Current Control

The input current like the output voltage is directly generated by the output current and it is obtained by discontinuous sampling from the output current wave form. If the switching frequency of the matrix converter is set at the highest input or output frequency, the input current of the converter will be sinusoidal and the magnitude of the harmony will display little harmonic content around the switching frequency. " Figure.5" shows the input current of the converter matrix at 2 KHz switching frequency. The remarkable thing is that the magnitude of the harmonic elements is comparable to that of the initial magnitude. Evidently, an input filter will be required for decreasing the harmonic elements of the input current to an acceptable amount.



(Figure 5. Input Current Control)

3.3 controlling the input power coefficient:

The controllability of input power coefficient is another important characteristic of matrix converter.

4. How to control matrix converter

For most applications of Ac drive, it is better to use a compact voltage supply converter in order to generate a sinusoidal output voltage with a magnitude of variable frequency. It we use a converter having an indirect voltage. We need elements for energy storage, such as inductance and huge capacitors, causing an increase in the volume of converter and it is not desirable. There are no Dc links in matrix converters, and it can be smaller than the conventional indirect converters, because this converter needs a strategy for controlling. To control a matrix converter, we usually use these methods:

1) Controlling by ventuini method
2) Controlling by PWM
3) Controlling by SVM

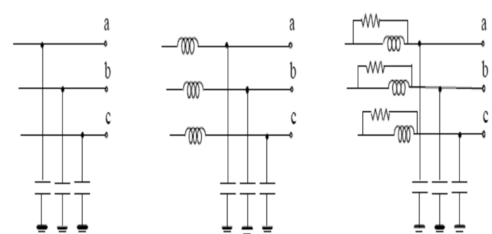
In this paper, controlling by SVM is taken into account. SVM method in comparison with venturini method which has been presented is simpler. This method provides a direct understanding of control and analysis of the performance of matrix converter for the pattern of switching.

Controlling by SVM method is performed in two ways.

1) Controlling of spatial veatial vector directly
2) Controlling of spatial vector indirectly

Since the MC is a direct frequency conversion device, the disturbances at the AC utility grid (line) side are immediately reflected to the load side. Line voltage source or impedance unbalances can result in unwanted input/output harmonic currents. [11] proposed a technique to eliminate the input current distortion due to the input voltage unbalance. The output voltage error caused by multistep commutation delay can be cancelled inherently by using three step commutations. Two compensation methods are proposed to improve the output waveform quality for different causes which uses the output current direction.

Knowledge of the extra harmonic loss is of particular importance for an integrated drive application where the motor cooling must be designed to remove the semiconductor device power loss in addition to the motor power loss. The results show that the extra harmonic loss and consequently the overall drive efficiency is affected by the choice of modulation technique. [11] analyzed method for evaluating power device losses of MC that consist of switching and conduction losses of IGBTs and diodes which is dependent on the modulation scheme. In most cases, for the removing of harmonic, LC filter is used. Some times RLC filters are used whose arrays are done as follows in " Figure". 6.



Filter C Filter LC Filter RLC

(Figure 6. Cases of filters)

5. Hardware development

The MC is still unpopular in industrial applications since it is not suitable for use with standard induction motors because the maximum voltage transfer ratio between the input and output can only be as high as" 86% ". [20] explored the viability of using direct power converter technology to realize integrated motor drives, at power levels significantly higher than is possible with traditional approaches, fitting within the same space envelope as an equivalent motor. The integrated motor design was targeted at pump and fan applications where the need to install motor drives in a separate location is often an impediment to the replacement of fixed speed motors. [19] proposed an adaptive modulation rate regulation method to

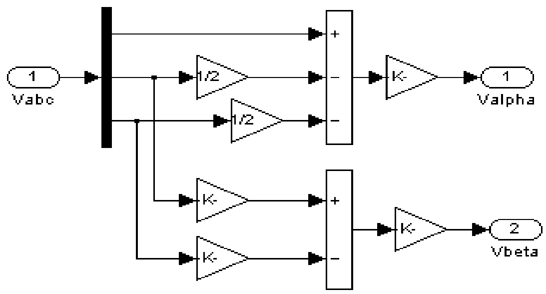
enhance the voltage transfer ratio. The mathematical expressions relating the input and output of the three phase matrix converter are implemented by using MATLAB/SIMULINK

Voltages v_β and v_α can be obtained from v_{abc} using the following formula:

$$v_\alpha = \sqrt{\frac{2}{3}} \times (v_\alpha - \frac{v_b}{2} - \frac{v_c}{2}) \qquad (1)$$

$$v_\beta = \frac{\sqrt{2}}{2} \times (v_b - v_c) \qquad (2)$$

And this is done in the method shown in Fig. 7.



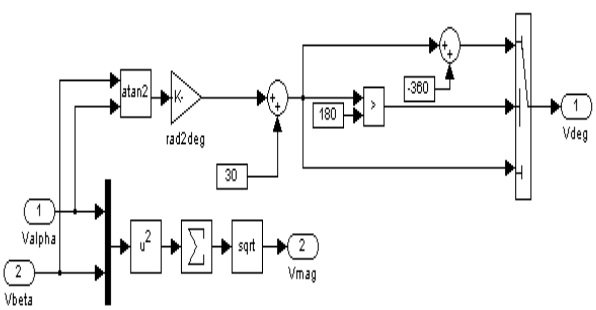
(Figure. 7. Bloch diagram of $v_\alpha , v\beta$)

Now, the absolute value and the angle of the reference or main vector is achieved through the following formula:

$$|v| = \sqrt{v_\alpha^2 + v_\beta^2} \qquad (3)$$

$$< v = tg^{1}(\frac{v_\beta}{v_\alpha}) \qquad (4)$$

And, the simulation of which is shown in “ Figure”. 8.



(Figure . 8. simulation of the reference vector)

the simulation of which is shown in “ Figure”. 8.

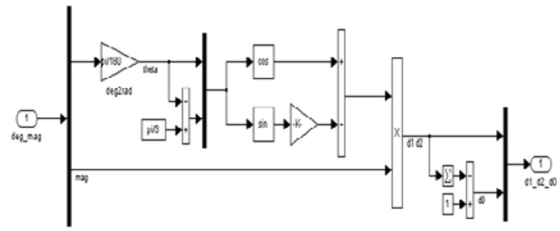
The time of activity of the active vectors can be calculated using the formula:

$$d\alpha = {}^{T\alpha}/_{Ts} = mv.\sin(\frac{\lambda}{3} \quad \theta v) \qquad (5)$$

$$d\beta = {}^{T\beta}/_{Ts} = mv.\sin(\theta v) \qquad (6)$$

$$dov = {}^{Tov}/_{Ts} = 1 \quad d\alpha \quad d\beta \qquad (7)$$

Thus the reference vector can be obtained using the formula $v_o = d_\alpha v_\alpha + d_\beta v_\beta$, And in this way the complex below in Fig. 9 can be designed:



(Figure. 9)

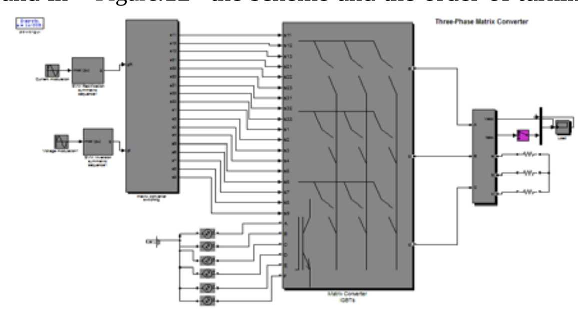
Finally, by taking into account the four points mentioned, a symmetric sequence can be designed at the end part of the indirect modulation block.

6. Simulation and results

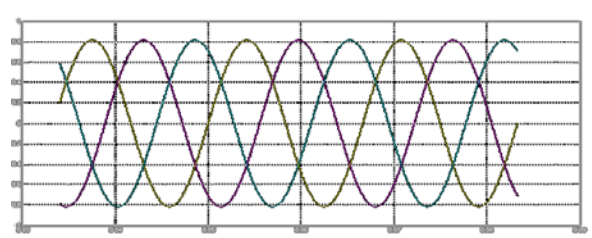
Description of circuit: This system consists of a six-based matrix converter which uses 18 back-to back “ IGBT” switches. The matrix converter is excited by a resistant static load of frequency of 6oHz. The switching algorithm is based on the indirect spatial vector modulation. This matrix converter acts like a rectifier and inverter connected through a DC link without any energy dissipation. The indirect spatial vector modulation enhances the direct controlling of the input current and the output voltage, thus allowing the power supply coefficient to be controlled. The general scheme of simulation is shown in “ Figure10”..

(Figure.10. Simulation of the system)

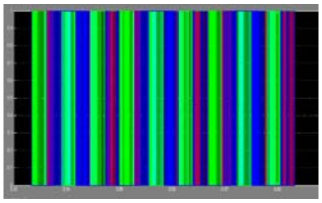
In “ Figure 11” the input of six phased SVM current is shown, and in “ Figure.12” the scheme and the order of turning on the



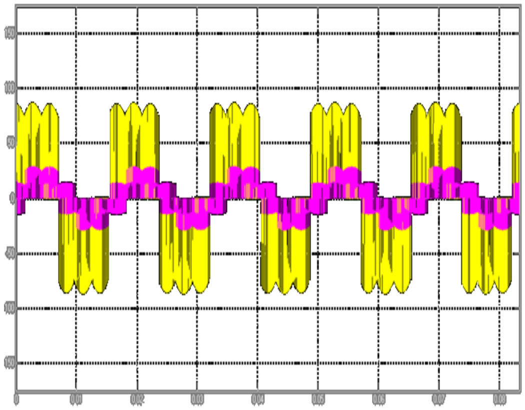
switches is shown. “ Figure . 13” shows Waveform current and output voltage.



(Figure . 11. The input of six phased SVM current . The input current like the output voltage is directly generated by the output current and it is obtained by discontinuous sampling from the output current wave form.)



(Figure .12. The scheme and the order of turning on the switches. The switching algorithm is based on the indirect spatial vector modulation. This matrix converter acts like a rectifier and inverter connected through a DC link without any energy dissipation.)



(Figure. 13Waveform current and output voltage)

7. Conclusion

In comparison to supply current and voltage inverters, matrix converters have many advantages. A matrix converter does not need the components of energy storage like huge capacitances and inductances in the course of the DC link. By using modulation strategies sinusoidal input–output waveforms with the least harmonic components and the displacement of input coefficient can easily be obtained. Moreover, this type of converter can be used for converting power and AC drive. But another important drawback that has been present in all evaluations of MC was the lack of a suitably packaged bidirectional switch and the large number of power semiconductors. This limitation has recently been overcome with the introduction of power modules which include the complete power circuit of the MC.

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